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A NEW METHOD OF EVALUATING THE EDGE SHARPNESS AND TRANSFER CHARACTERISTICS OF PHOTOGRAPHIC MATERIALS

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Translation of "Novyy metod otsenki krayevoy rezkosti i peredatochnykh khapakteristik fotograficheskikh materialov

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A NEW METHOD OF EVALUATING THE EDGE SHARPNESS AND TRANSFER CHARACTERISTICS OF PHOTOGRAPHIC MATERIALS

T. Barna

ABSTRACT: The concept of logarithmic modulation transfer function is introduced. It is related to acutance, and so allows determination of edge sharpness in all practical cases. Several films are evaluated by the new method.

STATEMENT OF PROBLEM

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The Jones and Higgins objective method of evaluating sharpness agrees well with its subjective perception [1]. Theoretically, however, the measurement of the modulation transfer function (MTF) is a more valid and universal method of evaluating sharpness, allowing judgments to be made not only about the individual elements of the photographic (or cinematographic) process, but also about the properties of the complex, image-forming system [2].

The acutance, according to Jones and Higgins, is an empirical characteristic, which cannot be simply calculated from the MTF. In fact, as is known, the MTF is independent of the average light level and depth of modulation, whereas the sharpness (or acutance) is greatly different in the shadows, half-tones and highlights of a photographic image. For photographic materials with the same MTF but characteristic curves of different shape the sharpness will also be different. Thus, the MTF does not give complete information about sharpness without the shape of the D(lg H) curve and the exposure conditions taken into account.

In this work the concept of the logarithmic modulation transfer function (MDF) is introduced. It is related to the spatial frequency N or angular frequency $\omega = 2\pi N$; the average optical density value $\bar{D} = \frac{D_1 + D_2}{2}$, where D_1 and D_2 are the maximum and minimum densities in an edge image, and the amplitude (density difference) $\Delta D = D_1 - D_2$. The parameter α, describing the MDF, is simply related to the acutance value and allows one to evaluate the sharpness in any practical case. The MDF possesses a property analogous to the MTF with respect to calculating the transfer characteristics of a complex photographic system, consisting of several separate elements. The MDF can be calculated if the density distribution in the edge trace is known.

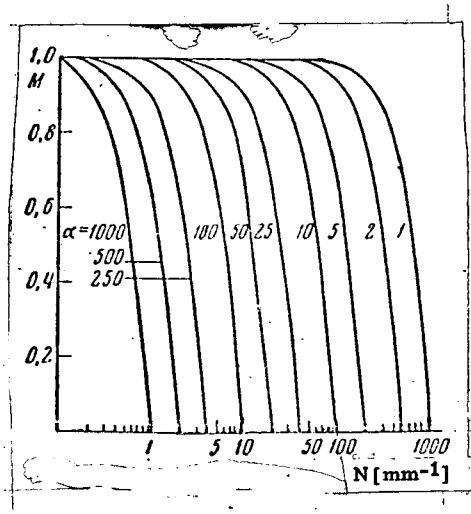

Figure 1. Series of MDF's for different values of the parameter α.

THEORETICAL CONSIDERATIONS

A light-sensitive layer produces a more or less distorted, smeared, image of a perfectly sharp edge. The photographic material can be considered as an

*Numbers in the margin indicate pagination in the foreign text.

information transfer system, in this case a density distribution transfer. This density can be represented in the form of some summation of spatial frequencies. If the input signal D(x) (the density distribution for an edge in the ideal case when the emulsion layer does not scatter light) and the output signal D'(x), characterizing the density distribution in the actual photographic image, are known, then it becomes possible to compute the MDF for a given density distribution.

Using the Fourier transformation for the output $D'(\omega)$ and input $D(\omega)$ signal, in the general case we obtain /25

$$\text{MDF} = D'(\omega) / D(\omega). \tag{1}$$

It can be shown [3] that with an accuracy adequate for practical cases the absolute value is:

$$\text{MDF} \simeq \frac{\sin\left(\frac{\Delta D\omega}{2\bar{g}(x)}\right)}{\frac{\Delta D\omega}{2\bar{g}(x)}}, \tag{2}$$

where the average gradient of the edge trace is

$$\bar{g}(x) = \sqrt{1/k \sum_{n=1}^{k} \bar{g}(x)}, \quad n = 1, 2, 3 \ldots . \tag{3}$$

Equation (2) is invariant only in the case when the parameter $\alpha = \Delta D / \bar{g}(x) = \text{const.}$ In actuality for the same photographic material and given development conditions this parameter depends on the optical density modulation ΔD and the average density $\bar{D}$. Thus, the MDF is a function of three independent variables: N, ΔD and $\bar{D}$. A series of MDF's for different α and N values is shown in Fig. 1.

The solution is done in two steps. Initially the edge function (Fig. 2) is determined from the given density distribution for the edge with the aid of the D(lg H) curve. Then the parameter α, describing the MDF, is calculated from the edge function obtained for the given conditions. It is obvious, that different portions of the photographic image—shadows, halftones and highlights—will correspond to different edge functions, as shown schematically in Fig. 3.

The acutance, according to Jones and Higgins, is determined [1] from the equation:

$$A = \frac{1}{\Delta D} \frac{1}{k} \sum_{n=1}^{k} \bar{g}^2(x) n, \tag{4}$$

where k is the number of regions of the edge traced to be summed. The relationship

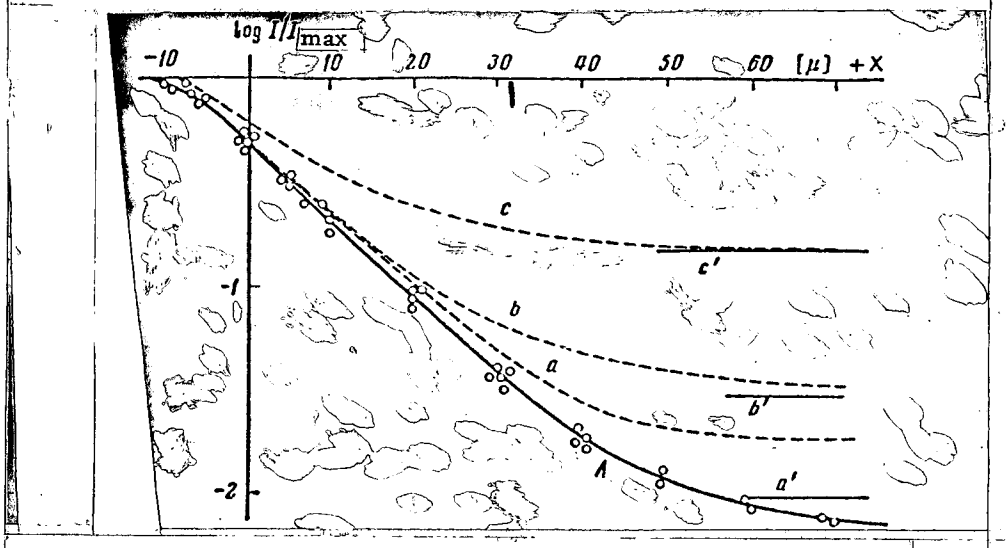

Figure 2. Edge functions, characterizing on a logarithmic plot the intensity distribution in a light-sensitive layer. A—original curve of function, obtained from results of density measurements of edge followed by photographic calibration against the characteristic curve; a, b, and c are edge functions, corresponding to different intensity levels, obtained by calculation from curve A.

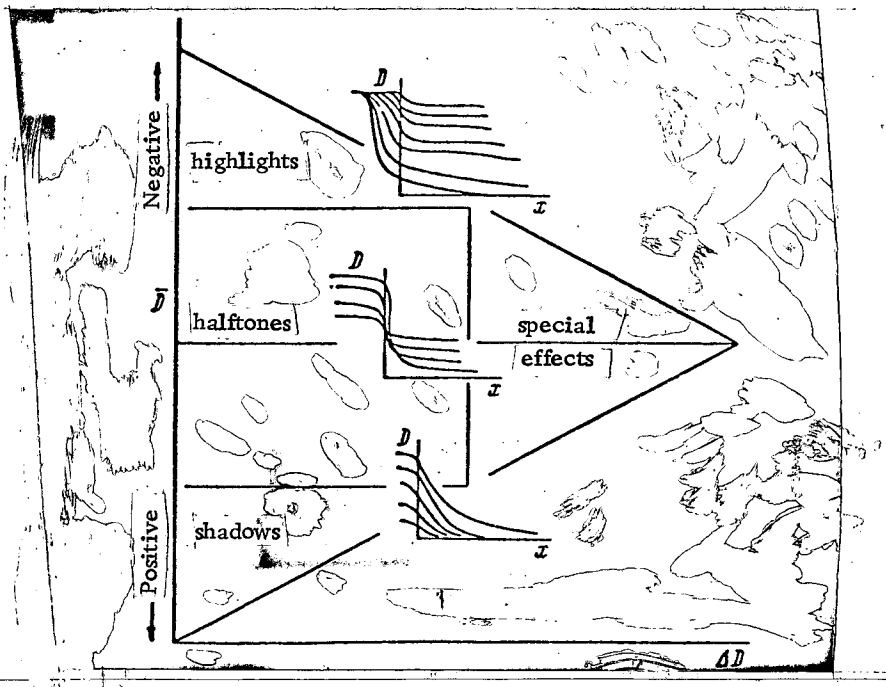

Figure 3. Density distribution at boundary between highlight and shadow portions of photographic image in the shadow, halftone and highlight regions.

between the quantity α and the acutance is defined by the simple equations: /26

$$\alpha = \sqrt{\frac{\Delta D}{A}} \text{ and } A = \frac{\Delta D}{\alpha^2} \quad (5)$$

The parameter α can be used to evaluate the properties of a complex system, for example the copying process. The resulting value is:

$$\alpha_{res} \approx \sqrt{\alpha_1^2 + \alpha_2^2}, \quad (6)$$

where α_1 and α_2 are the characteristics of the negative and positive material.

Thus, using the MDF allows one to solve two problems: to obtain an objective evaluation of the sharpness and transfer properties of a photographic material.

METHOD

The edge function of the photographic material to be studied is obtained in the following manner. The emulsion layer is placed in a step sensitometer in intimate contact with a screen of 20-μ thick steel sheet with a very smooth edge. After exposure and processing in a developing machine, edge images with a broad range of exposure variation are obtained on all steps of the sensitometer strip.

The D(lg H) curve is measured from the sensitometer strip in the usual manner, after which the density distribution in the edge image is determined for the different portions of the sensitometer strip by means of a recording microphotometer. A Zeiss microphotometer, somewhat modified, with an amplifier and recorder is used. Immersion micro-objectives with a 1.25 aperture (90X) are used as the condenser and objective lenses.

The portion to be measured is cemented between a microscope slide and cover glass with Canadian balsam. Photometric measurements are made using oil immersion. /27
The effective dimensions of the scanning slit of the microphotometer are 0.7x100 μ. The range of measured densities is variable from 0-0.5 to 0-3.75 optical density units, with a measurement accuracy of $\pm 1\%$ of the maximum value. The microphotometer equipment has been used since 1958 in the "Mafil'm" studio in Budapest. More detailed data on this equipment have been published earlier in [3, 4].

The original edge function lg I(x) (see Fig. 2) is calculated from the series of edge traces D(x), describing the density distribution (Fig. 4), and the characteristic D(lg H) curve of the photographic material. Having this edge function, corresponding to the maximum difference in edge response, one can calculate a series of edge functions for other exposure conditions, as shown in Fig. 2.

From these data, using D(lg H) and different specified values of ΔD and $\bar{D}$, one calculates the density distribution D(x) for a large series of edge traces, as shown schematically in Fig. 3. For each edge trace its average gradient is determined between

the initial and final portions x_0 and x_f, for which the optical density exceeds 0.005 per micron.

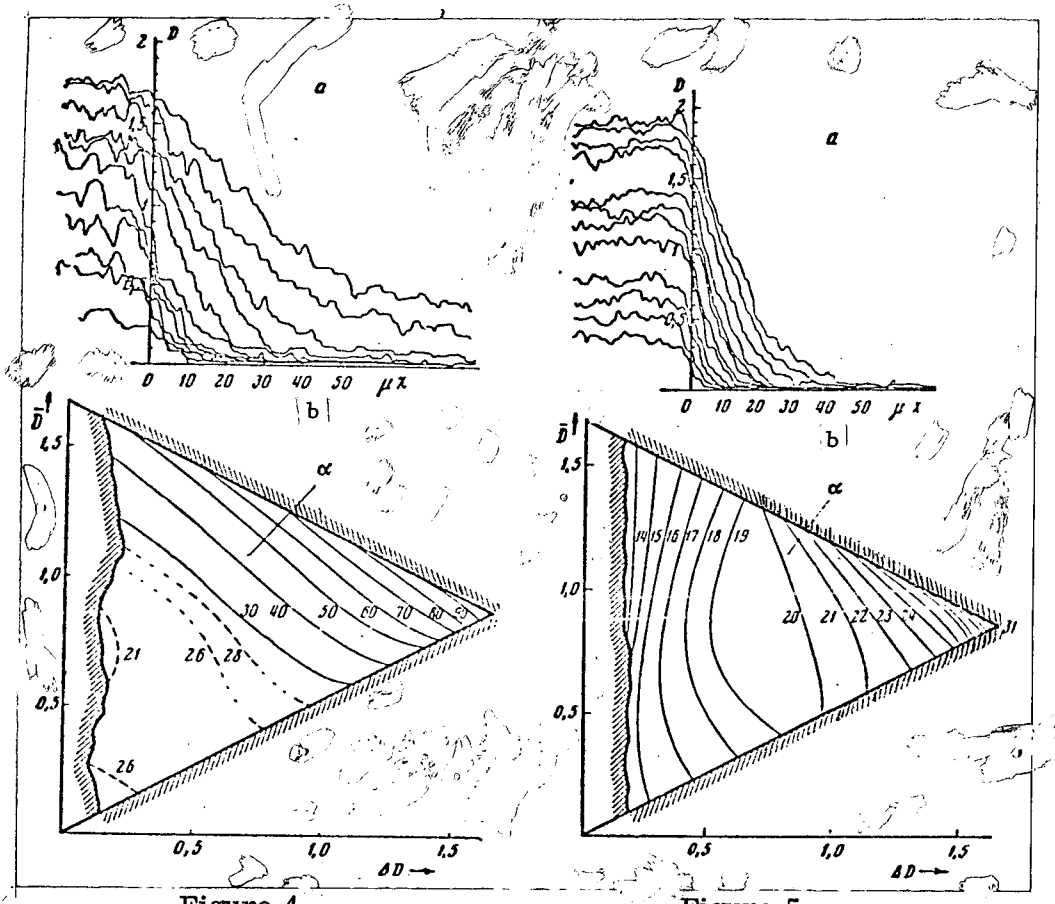

Figure 4

Figure 5

Figure 4. Edge curve traces (a) and isolines of the parameter α (b); ORWO NP-5 negative motion-picture film.

Figure 5. The same for ORWO NP-55 negative motion-picture film.

After having determined in this manner the quantity $\bar{g}(x)$ from Equation (3) and specified by the corresponding ΔD values, the values of α, describing the MDF's for the given conditions, are calculated on the basis of the relation (5).

INVESTIGATION RESULTS

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Figures 4 and 5 show traces of the edge curves D(x) and the values of the parameter α calculated from these data by the method described above. The numbers, characterizing the quantity q, are provided by the α isolines, where this parameter has a given value.

The difference in sharpness between the ORWO NP-5 and ORWO NP-55 negative motion-picture films is clearly evident from the edge traces and the triangular diagrams of Figures 4 and 5. It is easy to trace the dynamics of the parameter α as a function of the average optical density $\bar{D}$ of the edge curve and the density difference ΔD between the highlight and shadow portions. The sharpness decreases with an increase in ΔD, but for the NP-5 film in the region of halftones and special effects this falloff in sharpness occurs much faster.

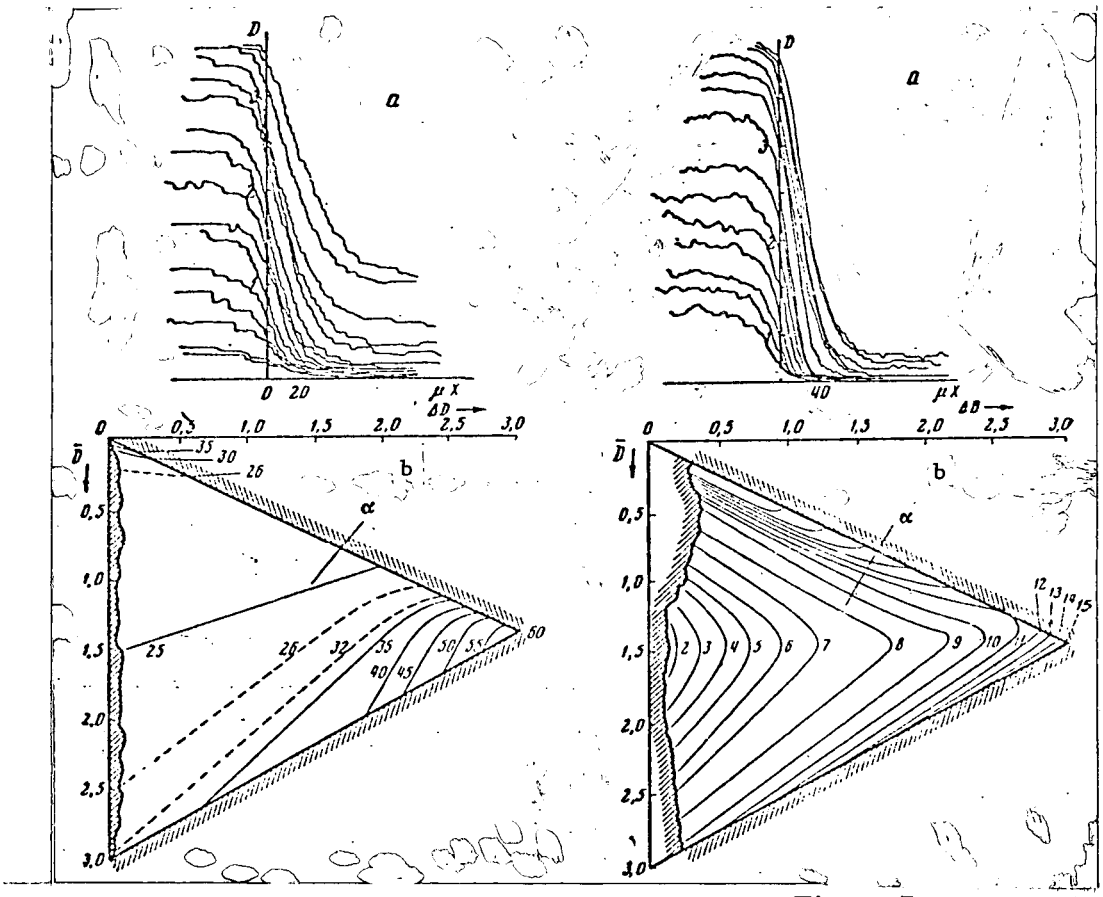

Figure 6

Figure 7

Figure 6. Edge curve traces (a) and isolines of the parameter α (b) of a positive motion-picture film, exposed in white light.

Figure 7. The same for exposure in the UV band.

The change in sharpness of a positive motion-picture film as a function of the spectral band used is shown in Figures 6 and 7. Changing from exposure with a conventional light source (incandescent lamp) to exposure in the UV band produces a very appreciable gain in sharpness.

The method we have discussed can be used to evaluate the sharpness not only of negative and positive films, but also to obtain the resulting characteristic of the printing process under these or other conditions. Figure 8 shows triangular diagrams that char-

acterize the sharpness of the positive image obtained in the process of printing from NP-55 negative onto a positive film with white light and UV exposure. In the latter case it is possible to obtain a positive image with practically no decrease in sharpness compared with the original negative (compare with Figure 5). /29

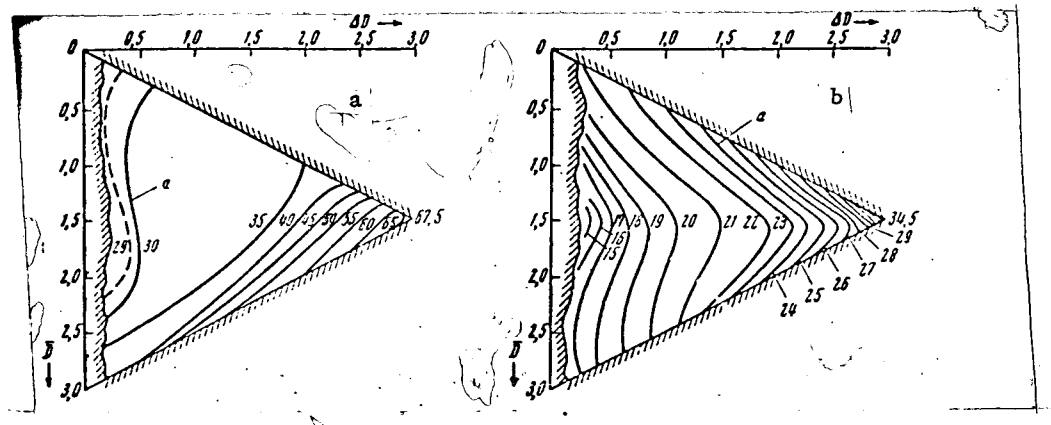

Figure 8. Negative-positive process. Printing from NP-55 negative onto positive motion-picture film; exposed in white light (a) and in UV band (b).

Instead of the diagrams, for solving many practical problems it is sufficient to use the most pertinent average values of the parameter α: $\bar{\alpha}$ - the average value for the entire area of the triangle diagram; α_{hl} - the average value for the highlight regions; α_{ht} - the average for the halftones; α_{sh} - for the shadows, and α_{eff} for special illumination effects when the contrast between the highlight and shadow portions of the object being photographed is very high. /30

Experimental data for several motion-picture films and printing conditions are listed in the table.

The data in the table provide fairly complete information on the image sharpness under various conditions. It is easy to verify that the resulting copy sharpness, measured experimentally, agrees satisfactorily with that calculated from Equation (6). It follows from Equation (6) and test results that for full achievement of the sharpness of a negative it is necessary that the sharpness of the positive material be about 3-4 times better than for the negative. This is the case when UV radiation is used in the printing process. Here, the copy sharpness for printing from Double-X or NP-55 is practically no different from the negative sharpness. At the same time, printing in white light for a negative with good sharpness (NP - 55) leads to a significant reduction in image quality. For negative materials with poor sharpness, such as NP-5, changing from white light exposure for printing to UV provides no marked advantage in sharpness.

In analyzing the test results it should be taken into consideration that the visual perception of image sharpness is proportional to the square of the parameter α. Therefore, for example, a change in the value of α from 42 to 29 μ (see No. 9 and 11, in the table) will be perceived visually as a factor of 2 increase in image sharpness. This rule agrees well with the visual estimate of image sharpness from a projection onto a screen. Thus,

in particular, changing from copy printing from Double-X negatives in white light to printing in the UV band has made it possible in Hungary to go from a 1:1.5 format to a 1:1.85 format for the same picture height with no loss in image quality.

No.	Test conditions	$\bar{\alpha}$	α_{hi}	α_{ht}	α_{sh}	α_{eff}
1	Double-X Kodak	28	23	25	28	37
2	Plus-X Kodak	30.5	33	25	20	45
3	NP-5 ORWO	42	45	30	26	55
4	NP-50 ORWO	30	31	26	22	40
5	NP-55 ORWO	18	16.5	17	17	22
6	Positive motion-picture film, exposed in white light	30	26	25.6	32	40
7	The same, exposed in blue band	20	18	16	20	30
8	The same, exposed in UV band	7.5	9	6.5	8	9.5
9	Copy from Double-X negative onto positive motion-picture film; exposed in white light	42	34	37	40	55
10	The same, exposed in blue band	34	28	29	36	45
11	The same, exposed in UV band	29	26	25.5	28	38
12	Copy from NP-5 negative onto positive motion-picture film; exposed in white light	46	45	37.5	39	40
13	The same, exposed in UV band	39	45	30	27	60
14	Copy from NP-55 negative onto positive motion-picture film; exposed in white light	37	31	31	37	50
15	The same, exposed in UV band	21	21.5	20	19	24

Data obtained by the method we have reported here make it possible to solve a complex set of technological problems, arising during film cinematography, in the processes of contrasting and printing motion-picture films. They are used for black-and-white as well as color materials. Over a period of many years at the Mafil'm studio in Budapest the objective sharpness chracteristics in terms of the parameter α have matched well against the practical evaluation of image quality.

The logarithmic modulation transfer function (MDF) combines a numerical evaluation of photographic image sharpness with the characteristic of the transfer properties of light-sensitive materials. The parameter α, being very simply related to the Jones and Higgins concept of acutance, permits determining the properties of a complicated image-forming system, such as a negative-positive process or the process of contrasting. In addition this characteristic allows one to make a numerical evaluation of the sharpness of different portions of the image (or motion-picture frame), such as halftone, highlight and shadow, as well as the area of special effects. It has been established that such an

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evaluation of the properties of negative and positive materials and the copying process agrees well with the visual perception of the image.

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